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# Hydropneumatic Suspension

The invention relates to a hydropneumatic suspension having at least one suspension cylinder and at least one suspension accumulator, in particular a hydraulic accumulator with a pilot-actuated valve, specifically a proportional valve for opening or blocking a fluid-carrying connection between suspension cylinder and suspension accumulator.

Hydropneumatic suspensions such as this are used, for example, as rear-axle suspensions in tractors or other machines. If a fluid-carrying connection is established between suspension accumulator and suspension cylinder by way of the pilot-actuated valve, especially one in the form of a conventional hydraulic accumulator or working cylinder which is connected to the respective wheel set of the tractor or machine, the wheel axis in question for the respective operating application is correspondingly spring-suspended. If it is now desired to use the machine, especially one in the form of a tractor, to carry out operating processes such as plowing of a field with plowing equipment, the suspension is to be blocked, that is, the connection between suspension cylinder and suspension accumulator is interrupted by way of the pilot-actuated valve. This presents the advantage that the "working height" of the plow or other equipment may not be changed unintentionally, something which might impair the respective application intended.

The known technical solutions such as are commercially available normally employ purely electric actuation of the pilot-actuated stop valve for the associated stopping of the hydropneumatic suspension and, since this pilot-actuated valve is configured to be quite large in view of the volumes of flow to be controlled, high actuating forces are required in order to switch the valve, this in turn leading to use of switching magnets of correspondingly large size for actuation of the valve, ones which require correspondingly high electric power consumption. In addition, when the hydropneumatic suspension is at rest, the pilot-actuated valve assuming its blocked position, the respective drive configuration is rigid by design and effects exerted on the operating equipment, for example, by uneven ground over which the tractor or machine is operated, have the result that the respective disruptive influences are transmitted to the operating equipment, such as a plow, something which may significantly impair the plowing process itself, the vehicle of course always being designed to be more rigid from the viewpoint of its driving behavior than control of the plow permits at all for an operating process such as plowing or the like. In the case of the disclosed solutions it frequently occurs during the unblocking process, which takes place rapidly, that any difference in pressure between suspension cylinder and pressure accumulator which may be present is very quickly equalized, this resulting in "bouncing" of the vehicle.

The proximate state of the art in the form of DE 42 42 448 C1 relates to a hydropneumatic suspension assembly for vehicles with high load ratios, in particular for tractors with means for mounting of cultivators and load-sensing pumps for pressure generation, pressure also being applied to the annuli of the suspension cylinders and the latter being connected to a hydraulic accumulator. Known configurations of this type have control mechanisms which must be fed by constant-pressure systems and in which use of a load-sensing pump is of no avail, since it would always have to deliver against high pressure. These known systems also present the disadvantage that they continuously consume energy. According to the solution disclosed in DE 42 42 448 C1, conservation of energy and the possibility of using a load-sensing pump are

achieved in that the annulus is supplied with pressure by way of a 3-way pressure control valve and a level control assembly having a valve assembly is provided which is briefly activated and deactivated only when static load changes occur and removes pressure from all control and feed lines in the position at rest which is otherwise assumed, the piston chambers and annuli being hermetically sealed off by way of return valves that may be unblocked.

Even with this known solution the possibility is not excluded of movements occurring unintentionally at the vehicle during the unblocking process because of the pressure difference which may be present.

On the basis of this state of the art, such as is applied in a large number of tractor and machine designs available on the market, the object of the invention is to avoid the problems referred to and in particular also to create a compact and energy-efficient valve control assembly for hydropneumatic suspensions which ensures both control of large volume flows and "gentle" unblocking of the hydropneumatic suspension. The object as thus formulated is attained by means of a hydropneumatic suspension having the characteristics specified in claim 1 in its entirety.

In that, as is specified in the characterizing part of claim 1, the pilot-actuated valve may be moved to the blocked position by means of a hydraulic actuating mechanism, in that the hydraulic actuating mechanism taps the fluid pressure between suspension accumulator and respective associated suspension cylinder and forwards it by way of a valve, a switching valve in particular, to an actuating side of the pilot-actuated valve by way of at least one pilot-actuated line, and in that there is introduced between the one valve and the pilot-actuated valve another valve, a proportional valve in particular, to which the respective associated pilot-actuated line is connected, the suspension configuration claimed for the invention both makes it possible to control large volume flows and allows slow release of the suspension, so that any pressure

differences present between suspension cylinder and pressure accumulator may be equalized slowly and so that the undesirable "bouncing" of the vehicle or the machine is reliably prevented.

The release mechanism, based essentially on a hydraulic concept, is structurally compact and cost effective in production. Since a hydraulic medium is already used to produce the hydropneumatic suspension, another type of energy (electric current) obviously need not be used to operate the respective suspension, this in turn lowering the production costs and maintenance effort. It has been found to be especially advantageous to employ a proportional pressure control valve as second valve. In one preferred embodiment of the hydropneumatic suspension claimed for the invention provision has been made such that the pilot-actuated valve has two actuation sides, one with a pilot operating component and the other with a reset spring, and such that both actuation sides are connected to a fluid line in the form of a first and a second pilot-actuated line. In another preferred embodiment of the hydropneumatic suspension claimed for the invention provision is made such that the proportional pressure control valve is mounted between the first valve and a branch which is connected both to a fluid-carrying connection to the tank and to the second pilot-actuated of the pilot-actuated valve.

As an alternative, in another preferred embodiment of the hydropneumatic suspension claimed for the invention, provision may be made such that the proportional pressure control valve is connected to the first pilot-actuated line and such that there is connected to this proportional pressure control valve in the branch a return valve which opens in the direction of the pilot-actuated component of the pilot-actuated valve.

In the case of the last-named embodiment provision may also be made to advantage such that the proportional pressure control valve connected to the first pilot-actuated line is secured from an unintentionally wrong direction of fluid flow by return valves as a type of bridge circuit.

By preference a proportional valve, in particular one in the form of a 2/2-way valve, is used as pilot-actuated valve and the first valve or switching valve in the form of a 2/3 way seat valve, in production of the hydropneumatic suspension.

The hydropneumatic suspension claimed for the invention is described in detail in what follows on the basis of three exemplary embodiments illustrated in the drawing. Each of the three figures, in the form of diagrams not drawn to scale, illustrates a hydraulic circuit diagram of the hydropneumatic suspension of one exemplary embodiment.

The hydropneumatic suspension presented in FIG. 1 has a suspension cylinder 10 of the conventional design. The suspension cylinder 10 is provided with a piston rod unit 12 and an axletree of a corresponding wheel set (not shown) is mounted on the free end of this piston rod of this unit. As the piston rod unit 12 moves back and forth inside the suspension cylinder 10, a hydraulic medium is moved in and out in the conventional manner in the two working spaces 14, 16, so that the respective details will not be discussed at this point.

As is to be described in detail in what follows, the suspension cylinder 10 is connected for operation to a suspension accumulator 18 in the form of a conventional operating or hydraulic accumulator such as one in the form of a diaphragm or bladder accumulator, a separating mechanism (not shown) in the form of a separating diaphragm or separating bladder separating the hydraulic medium for the suspension from a supply of gas in the accumulator the pressure cushion of which also determines the rigidity of the respective suspension cylinder 10. The configuration in question is for the most part also conventional for hydropneumatic suspensions and it as well will not be discussed in detail in this connection.

What remains to be determined, however, as has been indicated, is how a suspension cylinder 10 may be associated with a suspension accumulator 18; but configurations are also

conceivable in which suspension cylinder 10 and suspension accumulator 18 are present in a plurality of arrangements and a suspension accumulator 18 may actuate several suspension cylinders 10 correspondingly for their spring deflection processes. There is inserted between the suspension cylinder 10 and the suspension accumulator 18 a pilot-actuated valve 20 which is shown in FIG. 1 in its neutral position, that is, in its switched, released, open position in which the working space 14 of the suspension cylinder 10 is connected to the fluid side of the suspension accumulator 18 so as to carry fluid and accordingly forms the hydropneumatic suspension for the wheel set and axletree (not shown).

The pilot-actuated valve 20, especially in the form of a proportional valve, may be moved to the blocked position by way of a hydraulic actuating assembly designated as a whole as 22; in this blocked position the fluid-carrying connection is interrupted as regards such fluid connection between suspension cylinder 10 and suspension accumulator 18 relative to the pilot-actuated valve 20. The hydraulic actuating assembly 22 in question taps the fluid pressure between suspension accumulator 18 and the associated suspension cylinder 10, specifically between suspension accumulator 18 and valve 20 and delivers this pressure by way of a switching valve 24 to one of the operating sides 26 of the pilot-actuated valve 20. The pertinent tapping point between valve 20 and suspension accumulator 18 is designated as 28 in FIG. 1. The aforementioned switching valve 24, in the form of a 3/2-way seat valve, has, in addition to a first input 30, which is connected to the tapping point 28 so as to carry fluid, a second input 32 which is connected to the tank T of the hydropneumatic suspension by way of a connecting line 34. The switching valve 24 also has an output 36 to which a pilot-actuated line 38 is connected which engages the pilot-actuated component 40 of the valve 20 on the operating side 26 of the pilot-actuated valve 20. In addition to the first pilot-actuated line 38 there is for the other operating side 42 of the valve 20 another, second, pilot-actuated line 44 which communicates with the connecting line 34 leading to the tank T by way of a connection 46. A pressure spring 48 as reset assembly is connected by conventional means to the other operating side 42 to the valve 20.

Another valve in the form of a proportional-pressure control valve 50 as well is connected to the connecting line 34 between the second input 32 of the switching valve 24 and the connection 46. The opening characteristic for the respective valve 50 may be assigned conventionally by way of a control assembly 52, while the secondary branch line 54 connected to the connecting line 34 serves the purpose of tapping the pressure between proportional-pressure control valve 50 and the second input 32 of the switching valve 24. The control assembly as thus structured forms a sort of blocking unit 56, which in FIG. 1 is shown enclosed in a box drawn in broken lines.

For a better understanding of the function of the hydropneumatic suspension reference will now be made in detail to the illustration in FIG. 1. In the "open" position shown in FIG. 1, the pilot-actuated 2/2-way valve 20 connects the suspension cylinder 10 to the suspension accumulator 18. The pilot-actuated line 38 of this valve 20 is connected by way of the 2/3-way seat valve 24 as switching valve and by way of the proportional pressure control valve 50 to the tank T. The suspension is fully active in the respective "open" position.

If the suspension is now switched to the "blocked" position, for example, so as to permit proper operation with a piece of operating equipment such as a plow, mounted on a tractor, the switching valve 24 is actuated, in such a way that the suspension accumulator 18 is connected to the pilot-actuated component 40, one in the form of a pilot-actuated piston, for example, by way of the first pilot-actuated line 38. The entire pressure present in the suspension accumulator 18 may be used as pilot-actuated energy, and the hydraulically pilot-actuated valve 20 is switched to its blocked position, on the right as viewed in the line of sight to FIG. 1. The valve 20 is thereby closed and the suspension accumulator 18 thus disconnected from the suspension cylinder 10.

If it is desired now to relieve this blocked state over a relatively lengthy period, that is, to "unblock slowly," the 3/2-way valve 24 is to be switched and the output 36 of the valve 24 is

then connected to the second input 32 of this valve so that fluid may be carried. The pilot-actuated pressure of the pilot-actuated valve 20 present in the first pilot-actuated line 38 is then applied by way of the switching valve 24 to the proportional pressure control valve 50 so that here the proportional pressure control valve 50 can lower the pilot-actuated pressure by a specific amount. As a result of the specific lowering of the pilot-actuated pressure, the piston position of the pilot-actuated component 40 and accordingly the volume flow of the fluid to be transported between suspension accumulator 18 and suspension cylinder 10 may be determined precisely and adjusted. However, in that the valve 20 may be opened proportionally in relation to the actuating system of the pressure control valve 50, the unblocking process in question proceeds slowly and the so-called "bouncing" of the vehicle, such as one in the form of a machine such as a tractor or the like, cannot be caused unintentionally. If the valve 20 illustrated is in turn blocked, the amount of fluid displaced in the second pilot-actuated line 44 may be moved to the tank T by way of the connecting line 34.

In summary, the particular features of the hydropneumatic suspension are thus as follows. First of all, the pressure present in the suspension accumulator 18 is used to the fullest extent as pilot-actuated energy for the valve 20. The pilot-actuated pressure may be suitably controlled by the proportional pressure control valve 50, which may be connected to the pilot-actuated line 38. An axial displacement force is generated on the valve piston of the pilot-actuated component 40 by way of the pilot-actuated pressure; this force acts against the reset spring 48 of the valve 20, so that the piston position may be determined, and at the same time the amount of fluid transmitted between suspension accumulator 18 and suspension cylinder 10. In that the valve 20 may be opened slowly in the unblocking process, any difference in pressure which may be present between suspension cylinder 10 and suspension accumulator 18 may be slowly equalized, so that undesirable "bouncing" of the working vehicle in question is avoided during unblocking of the suspension.

For the sake of simplification the same reference numbers used for the switching and structural components in FIG. 1 are used in description of the following embodiments illustrated in FIGS. 2 and 3. The modified embodiments do nothing to alter the operating process as described in the foregoing and accordingly merely represent modifications of the embodiment illustrated in FIG. 1.

In the embodiment shown in FIG. 2, the proportional pressure control valve 50 is connected directly to the first pilot-actuated line 38 for the valve 20, a return valve 60 which opens in the direction of the pilot-actuated component 40 being connected to the secondary branch 58. In addition, tapping of pressure for the proportional-pressure control valve 50 is effected at a point between the valve 50 and a connecting point 62 for the return valve 50 in the first pilot-actuated line 38. Consequently, for a slow unblocking process, i.e., the slow opening of the valve 20, the quantity of fluid forced from the piston of the pilot-actuated component 40 is expelled by way of the proportional-pressure control valve 50 and the switching valve 24 in the position illustrated in the direction of the tank T. In the embodiment shown in FIG. 3 the proportional-pressure control valve 50 in this figure is in turn defined in the fluid carrying area of the first pilot-actuated line 38 for the valve 20 and is there suitably secured from a possibly false fluid flow direction by way of a hydraulic bridge circuit 64 in the form of a Wheatstone bridge. The bridge circuit 64 has four return valves 66 which may be moved in one of the branch circuits 68, 70 in pairs toward each other for their opened position. A connecting line 72 to which the proportional pressure control valve 50 is connected is positioned between a pair of return valves 66 in one of the branch circuits 68, 70. If unintentional reversal of the intended fluid flow direction occurs, the respective return valves are blocked and accordingly ensure that the pressure control valve 50 is correctly actuated from the proper side for slow unblocking of the valve 20.

The respective return valves 60 and 66 may also be spring-loaded and kept in their blocked position as a function of the respective application. For greater simplicity of illustration the reset springs in question have, however, been omitted.

The pneumatic pressure suspension configuration designed as a blocking unit 56 employs a pilot-actuated 2/2-way valve 50 for blocking and "gentle unblocking" of a pneumatic pressure suspension; large flow volumes may also be reliably controlled with the respective circuit configuration, and the solution in question is in addition cost-effective in production.